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GENERAL PROBLEMS OF BROADBAND AMPLIFICATION
IN THE MICROWAVE FREQUENCY RANGE

FC

CONTRACT N6-DR1-071 TASK XIX

Project No. NR-373-162



ELECTRICAL ENGINEERING RESEARCH LABORATORY
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS

FINAL REPORT
on
GENERAL PROBLEMS OF BROADBAND
AMPLIFICATION IN THE
MICROWAVE FREQUENCY RANGE

Contract No. N6-ori-071 Task XIX
Project No. NR 073 162

by

H. M. Von Foerster

31 March 1955

Electron Tube Research Section
Electrical Engineering Research Laboratory
Engineering Experiment Station
University of Illinois
Urbana, Illinois

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FINAL REPORT

on

Contract N6-ori-71 Task XIX

This represents the final report on Contract N6-ori-71 Task XIX: "General Problems of Broadband Amplification in the Microwave Frequency Range."

Since the research objectives of this contract were transferred to Contract N6-ori-07156, (which, effective 1 April 1956, became Contract Nonr 1834(08)), a short summary of the research work accomplished from the date of initiation of the subject contract (June 1, 1947) to the date of its expiration (March 31, 1955) will be given.

The research work carried out under the auspices of this contract was concentrated on three major areas:

- 1) the thermodynamics of the pure electron gas
- 2) analysis of UHF-modulated electron beams
- 3) general problems connected with the production of submillimeter waves.

1. Thermodynamics of the Pure Electron Gas

This study was aimed at a derivation of an equation of state for the pure electron gas (not ion-compensated) in order to get to grips with the problem of entropy-transfer and temperature change in accelerated electron beams. The results of this study are condensed in four technical reports (Series 3) and two publications.^{1,2} In the search for an appropriate vessel which would hold a stable electron cloud, the hollow spherical cathode was developed. Since the properties of this structure are still under investigation in different research laboratories,^{3,4} a technical report summarizing the known features of this cathode will be published by this laboratory under present contract Nonr 1834(08).

2. Analysis of UHF-Modulated Electron Beams

Since a large number of UHF amplifiers and generators employ pencil-shaped electron beams the electrons of which are supposed to interact with field supporting structures, a detailed knowledge of

density and velocity distribution of these electrons during one cycle of the electric field at a given point of interest is most desirable.

A beam analyzing system has been constructed, operating at a frequency of 3000 mcps, which allows the determination of the velocity and density distribution within one degree of the UHF cycle with an accuracy of a few percent. The time resolution of this analyzer is of the order of one micromicrosecond (10^{-12} sec). Its theory, design, and application are described in two technical reports (Series 5), one publication,⁵ and were presented in a paper read at the National IRE Convention in 1951.

The great versatility of this tool initiated a series of investigations^{6,7,8,9} which were carried out under the auspices of other contracts.

Some more specified beam studies are reported in Technical Reports Nos. 1 and 2.

3. General Problems Connected with the Production of Submillimeter Waves

It is of great advantage to consider the problems connected with the production of submillimeter waves from a thermodynamical viewpoint, particularly from the viewpoint of the second law of thermodynamics. The studies carried out under general area 1, as described above, illuminate this argument very well. Some of the results of this investigation are presented in Technical Report No. 4 and have been discussed in a paper delivered at the National IRE Convention in 1951.

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1. *On the Theory of Axial Symmetric Electron Beams in an Axial Magnetic Field* by A. L. Samuel
2. *Electron Bunching Phenomena in a Traveling Field* by H. Von Foerster and H. S. Wu
3. *Thermodynamics and Statistics of the Electron Gas*
 - 3-1 *Electrical Properties of a Stable Spherical Electron Cloud* - H. Von Foerster and H. S. Wu
 - 3-2 *Thermodynamical Properties of a Quasi-stable Spherical Electron Gas* - H. Von Foerster and H. S. Wu
 - 3-3 *Thermodynamics of the Electron Flow* - T. N. Chin
 - 3-4 *Determination of the Electron Temperature* - T. N. Chin
4. *Upper Frequency Limitations of Coherent Oscillators*
 - 4-1 *Oscillators with Resonant Energy Extractors* - R. Elliott
5. *Beam Analyzer*
 - 5-2 *Chromatic and Space Charge Aberrations in Circularly Deflected Electron Beams* - H. Von Foerster
 - 5-3 *Beam Analysis with a Circularly Deflecting System* - H. Von Foerster and L. R. Bloom

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1. Babcock, M. L., Holshouser, D. F. and Von Foerster, H. "Diode Characteristic of a Hollow Cathode," *Phys. Rev.* 91, 755 (1953).
2. Bloom, L. R. and Von Foerster, H. "Ultra High Frequency Beam Analyzer," *J. Appl. Phys.* 25, 649-653 (1954).
3. Chin, T. N. "Electron Temperature in the Parallel Plane Diode," *J. Appl. Phys.* 26, 418-423 (1955).

PAPERS PRESENTED AT MEETINGS

1. Bloom, L. R., Holshouser, D. F., Wu, H. S., and Cannon, W. W. "Beam Analyzer," *National Convention IRE, Paper No. 72* (1951).
2. Schaffner, J. S. and Von Foerster, H. "Guiding Principles in Production of Submillimeter Waves," *National Convention IRE, Paper No. 194*, (1951).

PERSONNEL

The chief director of the project was Dr. H. M. Von Foerster, Professor. The following persons were employed by the contract for the periods indicated:

<u>Name</u>	<u>Classification</u>	<u>Percent Time</u>	<u>Dates of Employment</u>
<u>Supervision:</u>			
Samuel, A.L.	Professor	25	June 1, 1946 to Aug. 31, 1949
Von Foerster, H.M.	Special Research Associate Professor	100	Sept. 1, 1949 to May 1, 1950
	Associate Professor	33 1/3	Oct. 3, 1950 to Aug. 31, 1951
	Professor	33 1/3	Sept. 15, 1951 to June 15, 1954
		17	Sept. 15, 1954 to Mar. 31, 1955
Bloom, L.R.	Research Assistant Professor	33 1/3	Sept. 1, 1946 to Aug. 31, 1951
		50	Sept. 1, 1951 to Aug. 31, 1952
<u>Administration:</u>			
DeVore, Lloyd T.	Professor	33 1/3	June 18, 1948 to Aug. 15, 1949
		5	Sept. 15, 1949 to June 15, 1950
Hoffman, J.W.	Research Associate Professor	10	Sept. 1, 1951 to Aug. 31, 1953
		5	Sept. 1, 1954 to Mar. 31, 1955
Mensendick, C.I.	Administrative Assistant	100	Aug. 1, 1948 to Dec. 1, 1948
<u>Research Associates and Assistants:</u>			
Babcock, M.L.	Research Assistant	100	Feb. 1, 1952 to Mar. 31, 1955
		75	Sept. 1, 1950 to Aug. 31, 1952
Brennan, L.E.	Research Associate	50	Oct. 16, 1947 to Feb. 1, 1950
Bryant, J.H.	Research Assistant	50	Sept. 20, 1946 to Sept. 16, 1948

<u>Name</u>	<u>Classification</u>	<u>Percent Time</u>	<u>Dates of Employment</u>
<u>Research Associates and Assistants(cont.):</u>			
Cannon, W.W.	Research Assistant	50	Dec. 3, 1946 to June 1, 1948
Chin, T.N.	Research Associate	100	Sept. 1, 1954 to Mar. 31, 1955
	Research Assistant	100	Sept. 1, 1951 to Aug. 31, 1954
		50	Mar. 1, 1951 to Aug. 31, 1951
Etter, J.E.	Research Associate	100	Oct. 1, 1946 to Sept. 1, 1948
Holshouser, D.F.	Research Associate	50	July 10, 1950 to Aug. 30, 1952
Hu, Huan C.	Special Research Associate	50	Sept. 20, 1946 to Dec. 1, 1948
Maier, E.	Research Assistant	50	Sept. 1, 1947 to August 1, 1948
Moulton, G.E.	Special Research Assistant	50	Aug. 1, 1947 to Oct. 1, 1948
Sen, S.M.	Special Research Assistant	50	July 21, 1947 to Oct. 16, 1947
Venema, H.J.	Research Assistant	50	Oct. 1, 1947 to June 1, 1948
Wu, H.S.	Special Research Assistant	50	Oct. 1, 1949 to Feb. 15, 1951
	Research Associate	50	Feb. 15, 1951 to Aug. 31, 1951

Technicians:

Charles, M.J.	Jr. Laboratory Mechanic	50	Feb. 17, 1948 to Aug. 13, 1948
Christoffers, W.H.	Jr. Laboratory Mechanic	50	June 9, 1947 to July 1, 1949
Franklin, I.R.	Jr. Laboratory Mechanic	100	Dec. 2, 1946 to Oct. 1, 1949
Lowe, J.F.	Instrument Maker	50	May 1, 1951 to June 30, 1954
McIntosh, V.	Jr. Laboratory Mechanic	100	Oct. 1, 1949 to Nov. 14, 1949
Pritchard, D.D.	Storekeeper	25	July 1, 1953 to March 31, 1955
Reed, F.F.	Jr. Laboratory Mechanic	25	May 12, 1947 to Dec. 8, 1949

<u>Name</u>	<u>Classification</u>	<u>Percent Time</u>	<u>Dates of Employment</u>
<u>Technicians, cont.:</u>			
Roth, W.	Instrument Maker	100	July 19, 1948 to Dec. 1, 1948
Waggener, R.N.	Senior Glassblower	33	July 1, 1951 to Mar. 31, 1955
Wilson, A.B.	Senior Electronics Technician	33	Apr. 1, 1953 to June 30, 1954
	Junior Laboratory Technician	33	May 1, 1951 to Apr. 1, 1953
<u>Clerical Assistants and Draftsmen:</u>			
Block, Ruth	Jr. Clerk Stenographer	50	Aug. 7, 1947 to Feb. 9, 1948
Kranz, W.B.	Draftsman	25	June 2, 1947 to Nov. 1, 1947
Harrawood, Gloria	Jr. Clerk Stenographer	50	Feb. 16, 1948 to Dec. 1, 1948
Sorensen, H.L.	Junior Office Appliance Operator	50	Feb. 7, 1949 to July 1, 1950
<u>Hourly Employees:</u>			
Chen, H. K.	Laboratory Assistant	Hourly	Feb. 20, 1948 to Apr. 29, 1948
Gempler, E.B.	Research Assistant	Hourly	Feb. 25, 1946 to Dec. 1, 1948
Matt, J.G.	Jr. Research Assistant	Hourly	Aug. 11, 1947 to Nov. 14, 1947
Roberts, R.F.	Jr. Research Assistant	Hourly	Oct. 14, 1947 to Sept. 11, 1948
Warrick, A.C.	Laboratory Assistant	Hourly	Sept. 15, 1948 to Dec. 1, 1948
Yoskowitz, Leo K.	Laboratory Assistant	Hourly	Feb. 9, 1948 to Dec. 1, 1948

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